THE EFFECTIVENESS OF THREE PHOSPHORUS SOURCES FOR PASTURE FERTILIZATION IN A CERRADO SOIL[1]

WALTER COUTO[2], GILBERTO LEITE[3] and CLÁUDIO SANZONOWICZ[4]

ABSTRACT - A field experiment with three phosphorus sources (triple superphosphate (TSP), thermal phosphate (TP) and phosphate rock (PR)) and two levels of lime was conducted in an acid oxisol of low fertility (clayey oxidic typic acrustox) to determine the amount of P required for establishment of a legume-based pasture, the relative efficiency of three sources and, the response to three rates of annual refertilization. The pasture was an association of *Andropogon gayanus* Kunth, var. *bisquamulatus* (Hoechst Hack) cv. Planaltina and *Stylosanthes capitata* (Vog) CIAT 1078. Best results were obtained with TP, specially during first and second year. This effect occurred at both 0 and 1650 kg ha^{-1} of Mg enriched lime (Calcium carbonate equivalent = 60.2). Forage yield obtained with 26 P kg ha^{-1} as TSP and PR at double rate (52 P kg/ha) increased with time, being similar to that obtained with TP (26 P kg/ha) by the fourth year. Annual refertilization at 13 and 26 P kg/ha improved yield during second and third years but yield increase due to annual refertilization decreased on time. Pasture response to annual refertilization depended on P source but was not affected by initial P rate. Despite the relatively high amount of P and other nutrients being applied, pasture establishment was very slow and forage yield considerably low, reaching 3.8 ton ha^{-1} $year^{-1}$ with best treatments.

Index terms: *Andropogon gayanus, Stylosanthes capitata*, refertilization, oxisols, red-yellow latosols.

EFICIÊNCIA DE TRÊS FONTES DE FÓSFORO PARA FERTILIZAÇÃO DE PASTAGENS EM SOLO DE CERRADO

RESUMO - Em um experimento de campo num Oxissolo de baixa fertilidade (clayey oxidic typic acrustox) (LV), foram testadas três fontes de fósforo: superfosfato triplo (ST), termofosfato (TF) e fosfato natural de Araxá (FA) e dois níveis de calcário, para determinar a quantidade de P necessária para o estabelecimento de uma pastagem consorciada, a eficiência relativa das três fontes, e a resposta às três doses anuais de refertilização. A pastagem de *Andropogon gayanus* Kunth, var. *bisquamulatus* (Hoechst Hack) cv. Planaltina, consorciada com *Stylosanthes capitata* (Vog) CIAT 1078. Os melhores resultados foram obtidos com o TF, principalmente no primeiro e no segundo ano. Esse efeito benéfico do TF ocorreu em 0 e 1.650 kg/ha de calcário enriquecido com Mg (equivalente em carbonato de cálcio = 60,2). A produção de forragem obtida com 26 kg/ha de P como ST e FA e com o dobro da dose (52 kg/ha de P) aumentou com o tempo, sendo similar à obtida com TF (26 kg/ha de P) no quarto ano. A refertilização anual com 13 e 26 kg/ha de P melhorou a produção no segundo e no terceiro ano, mas esse aumento de produção devido à refertilização decresceu com o tempo. A resposta da pastagem à refertilização anual dependeu da fonte de P, mas não foi afetada pela dose inicial de P aplicado. Apesar da quantidade relativamente grande de P aplicado e de outros nutrientes, o processo de estabelecimento da pastagem foi muito lento, e a produção foi consideravelmente baixa, alcançando 3,8 t ha/ano nos melhores tratamentos.

Termos para indexação: *Andropogon gayanus, Stylosanthes capitata, refertilização, Oxissolo, Latossolo Vermelho-Amarelo.*

INTRODUCTION

The large area in central Brazil known as the Cerrados (180 x 10^6ha) is dominated by oxisols. Those classified as red-yellow latosols in the Brazilian soil classification system cover more than 42% of the region and are among the most acid infertile oxisols. Those with a high clay content also have high P fixing capacities and very low cation exchange capacities (Goedert 1983).

Extensive areas of red-yellow latosols are covered by native vegetation dominated by grasses with small trees and shrubs, known as "campo sujo" and are used for extensive cattle grazing. Annual native pasture yield is less than 1000 kg ha^{-1} of dry matter (Couto et al. 1983a). The introduction of grasses tolerant to acidity in these soils with conventional P fertilizers has proved to be extremely slow, with low dry matter yield (Annual Report 1981). Exploratory research work conducted in

[1] Accepted for publication on 6 July, 1988.
Contribution from Centro Internacional de Agricultura Tropical (CIAT), Colombia and EMBRAPA/Centro de Pesquisa Agropecuária dos Cerrados (CPAC), Planaltina, Brazil.

[2] Eng. - Agr., Ph.D., Solano Antuña 2960, Aptº 502, Montevideo, Uruguai.

[3] Eng. Agr., Ph.D., EMBRAPA/Centro de Pesquisa Agropecuária dos Cerrados (CPAC), Caixa Postal 70023 CEP 73300 Planaltina, DF.

[4] Eng. - Agr., M.Sc., EMBRAPA/CPAC.

greenhouse and in the field showed that apart from well known soil P deficiency, Ca, Mg, Zn and Mo were also deficient for legume-based pastures (Couto et al. 1983).

Considering the high P fixing capacity of the soil (Le Mare 1982, Smith & Sánchez 1980), it could be expected that sources of P other than water soluble P fertilizers could be more efficient for pasture establishment and could have a greater residual effect. Thermal silico phosphate has been found more effective than superphosphate on high P sorbing soils (McLachlan 1981) with the additional advantage of supplying more Ca and Mg than triple superphosphate (TSP). This could eliminate the need for moderate amounts of lime applied to this soil to provide Ca and Mg to acid tolerant pastures. Low-solubility phosphate rock applied to acid soils with high buffer capacities for Ca and P has been found poorly effective when compared with water soluble P sources but their effectiveness increased with reaction time (Cabala-Rosand & Wild 1982).

A field experiment was established on a site representative of large areas of red-yellow latosols with "campo sujo" vegetation at the Centro de Pesquisa Agropecuária dos Cerrados (CPAC) (Cerrado Agricultural Research Center) of EMBRAPA: (I) to determine the amount of P required for establishment of a grass-legume pasture; (II) to compare the relative efficiency of three P sources; (III) to assess the need of additional application of Ca and Mg and (IV) to assess the effectiveness of annualy applied P rates against varying amounts of P applied at establishment.

MATERIALS AND METHODS

The experiment was conducted in a recently cleared area at an experimental site representative of large areas of the Cerrados, near Planaltina, DF, located 16° S Lat. Annual rainfall is 1570 mm, 80% of which falls between November and April. The soil at the experimental site is high in clay content (> 70 percent clay), presenting a very deep profile (> 1.80 m depth) with no textural changes. Some soil characteristics are presented in Table 1. The soil is classified as highly clayey, red-yellow latosol according to Brazilian soil classification. It has been classified as clayey, oxidic typic acrustox according to soil taxonomy (Estados Unidos 1975). The soil is known by its extremely low natural fertility and high P fixing capacity (Le Mare 1982, Smith & Sanchez 1980).

The experimental site occupies a level area within a high plateau that runs for several kilometers. Despite the high chroma and red-yellow soil color (7.5 YR 6/6 at 1.80 m depth), a seasonal watertable near the surface has been observed at the peak of the rainy season during some years. This conditions, which are suspected to occur in large areas of similar characteristics (Couto et al. 1985), are believed to contribute to lower yields as a result of poor root development and nutrient wash-out (Couto et al. 1983b).

Three P sources have been tested in the experiment: triple superphosphate (TSP), Thermal phosphate (TP) and a low-solubility phosphate rock (PR) from Araxá, Brazil. Thermal phosphate (TP) is a calcium-magnesium phosphate prepared by Fertilizantes Mitsui S.A. Araxá phosphate rock (PR) is a ground natural phosphate, 85% of which passes 200 mesh sieve (0.075 mm). Chemical composition of these products and TSP is presented in Table 2.

TABLE 1. Selected chemical characteristics of a soil profile near the experimental site.

Depth (cm)	Organic* matter ($g\ kg^{-1}$)	pH (1:1) H_2	Exchangeable cations (Al)	(Ca + Mg)	(K) cmol $(p^+)kg^{-1}$	P-Mehlich I ($Mg\ kg^{-1}$)
0-20	31	4.8	0.24	0.26	0.03	1.1
20-40	22	4.8	0.04	0.20	0.01	1.0
40-60	22	5.2	-	0.18	0.01	1.0
60-80	16	5.8	-	0.16	0.01	0.9

* Organic C x 1.72

TABLE 2. Chemical analysis of the phosphate sources ($g\ kg^{-1}$).

Product	P content Total	Soluble 2% citric acid*	water	(Mg)	(Ca)
		$g\ kg^{-1}$			
Triple superphosphate (TSP)	209	192	174.6	--	114
Thermal phosphate rock (TP)	78	72	--	88.4	200
Araxa phosphate rock (PR)	127	24	--	--	307

* 1:100 ratio.

Treatments consisted in three P sources applied at three P rates on the base of total P contained in each source. Phosphorus rates were 26, 52 and 104 kg of P ha^{-1} for TSP and TP, and 52, 104 and 208 kg of P ha^{-1} for P. One additional treatment consisting of a control (O P rate) was included and the resulting ten treatments allocated to 12 m x 12 m plots in a randomized complete block experimental design. A blanket application of K, S, Zn and Mo at 83, 50, 2 and 0.27 kg ha^{-1} respectively, as KC1, $CaSO_4.1/2\ H_2O$, $ZnSO_4\ 7.H_2O$ and $(NH_4)_6\ KMo_7O_{24}.4H_2O$, was used at establishment. All products were surface broadcast and lightly incorporated (7-8 cm depth) with a disk-harrow. No fertilizer had been applied previously. The area was planted with Andropogon grass (*Andropogon gayanus* Kunth, var.

bisquamulatus (Hoechst Hack) cv. Planaltina at 10 kg/ha^{-1} and *Stylosanthes capitata* (Vog) CIAT 1078 at 5 kg ha^{-1}. The seed was broadcast and covered with a compacting corrugated roller. These two forage species are known for their adaptation to acid infertile soils. The pasture was sown on November 9, 1978; growth during first rainy season was very slow. The first cut was made on May 1979, at the end of the rany season. Sampling area was 12 m x 1 m for each plot. Dry matter yield of each pasture component was determined and the tops were analized for P, Ca, Mg and K.

At the start of second rainy season all plots were divided into 6 m x 12 m sub-plots and lime levels of 0 and 1650 kg ha^{-1} were allocated at random within each main plot. Calcitic lime to which $MgCO_3$ was added to obtain a product containing 106 Ca and 82 Mg g kg^{-1} (Calcium carbonate equivalent = 60.2) was used in the experiment. Each sub-plot was also divided in three 6 m x 4 m sub-sub-plots and refertilization P levels allocated to each one at random, within sub-plots. Phosphorus refertilization levels were applied to sub-sub-plots annually at the start of the rainy season thereafter, at 0, 13 and 26 kg of P ha^{-1} on total P basis using same source initially applied. On control plots TSP was used for annually applied rates.

Each time pasture was cut at 8 cm height when forage modal height reached approximately 40 cm hight. Two to three cuts were made every year afterwards, with a total of nine cuts. Sampling area was 0.85 m x 6 m or 1 m x 6 m. All vegetation left on plots after sampling, was mowed down to sampling height, carefully chopped and left on the plot surface.

Forage samples were oven dried at 70°C for 72 hours, ground on stainless steel mill. Chemical analysis was performed after wet oxidation with H_2O_2 and H_2SO_4 using atomic absorption for Ca and Mg, flame photometry for K and absorption spectrophotometry for P.

Soil analysis was performed at the beginning of the experiment and on samples taken each year (August), at 0 cm - 15 cm depth in each sub-sub-plot, considering a set of eight individual cores for each composite sample. Samples were air dried, crushed, passed through 2 mm mesh and analyzed for extractable P and exchangeable K, Ca, Mg and Al. Soil pH was measured in water (1 : 1 ratio). Available P was extracted by Mehlich's I Method (Nelson et al. 1953) and Bray I Method (Bray & Kurtz 1945). Exchangeable Ca, Mg and Al were extracted with 1M KCl solution and K with Mehlich solution (0.025 M1/2 H_2SO_4 + 0.05 MHCl). Calcium and Mg were determined by complexometry, K by flame photometry and P by absorption spectrophotometry. Exchangeable Al was determined indirectly, by extractable acidity titration.

RESULTS AND DISCUSSION

The combined analysis of variance of eight cuts performed during second to fifth year showed significant differences in yield between cuts and between levels and P sources but no treatment x cut interaction was recorded. All cuts within a year have been added together and a new combined analysis of variance including year effect and treatment x year interaction was computed. Within the treatment x lime interaction, only P source x lime interaction was significant. Similarly, within the treatment x annual refertilization interaction, only P source x refertilization interaction was significant.

Results referred to hereafter in this paper correspond to total forage field, unless specifically indicated. Contribution of legumes to total forage yield will be discussed at the end of this paper.

Pasture response to initial P rates

Results will be discussed separately first, for each source, at both levels of lime, considering only initial P rates (0 level of annual refertilization). Quantitative relationships between forage yield, initial P rates, lime rates and year effect were estimated according to a linear or quadratic model of the type: $Y = B_0 + K_{yi} + K_{Li} + B_{1i}P + B_{2i}P^2$ where Y_i is kg ha^{-1} of forage yield per year for source i; K_{yi} is year effect on yield for source i, K_{1i} is lime effect for same source, P is the amount of P applied at the start of the experiment in P kg ha^{-1} and B_{1i} and B_{2i} are constants for source i. The values of all parameters are presented in Table 3. Mean values of annual forage yield actualy measured, for initial rate of all P sources, at 0 P annual rate of refertilization, are presented in Fig. 1. Results show that yield for PR at a rate of 52 P kg ha^{-1} was similar to lower level of other sources (26 P kg ha^{-1}) four years after application. Moreover, very little increase in yield was obtained by increased levels of P from this source. Also, forage yield obtained initially with phosphate rock and with TSP as well, were considerably lower than these obtained with TP, (Fig. 1). This could be attributed to initial low solubility of PR and P fixation from TSP in this acid, high clay soil. However, plant analyses performed on first and second cuts did not show a lower P content in tissue from plants growing in PR or TSP plots (Table 4). In fact, P content in plant tissue was low with all P sources despite the differences in yield, suggesting P was still limiting. Also, if P uptake is considered (not shown in Table 5), it could be concluded that available P to plants was higher with TP than with other P sources.

Effect of P source

Due to the large variation in yield between years the forage yield of P sources corresponding to 0, 13 and 26 P kg ha^{-1} annual rates (means of all initial P rates and lime) have been expressed as percent of

TABLE 3. Regression equations of forage yield (kg ha^{-1}) on applied P levels (P kg ha^{-1}) at planting, for three P sources and lime (TSP = Triple superphosphate; PR = phosphate rock; TP = thermal phosphate). Annual yield.

	R^2
Y (PR) = 2126*** + K_y + 2.21880***P	0.50
(159) (165) (0.89090)	
Y (TSP) = 713 + K_y + K_L + 56.11112***P - 0.33753**P^2	0.62
(390) (180) (127) (13.61591) (0.10005)	
Y (TP) = 1979 + K_y + K_L + 10.09331***P	0.40
(208) (202) (143) (2.18843)	

Notes:

1. Year effects (K_y) = -617, -704, +393, and 0 (PR), for years 80, 81, 82, 83.
   -666, -780, +381, and 0 (TPS), for years 80, 81, 82, 83.
   - 30, -445, +360, and 0 (TP), for years 80, 81, 82, 83.
2. Lime effects (K_L) = -385 (TSP) and -387 (TP) when not applied, annual average.
3. Figures within parenthesis are standard errors.

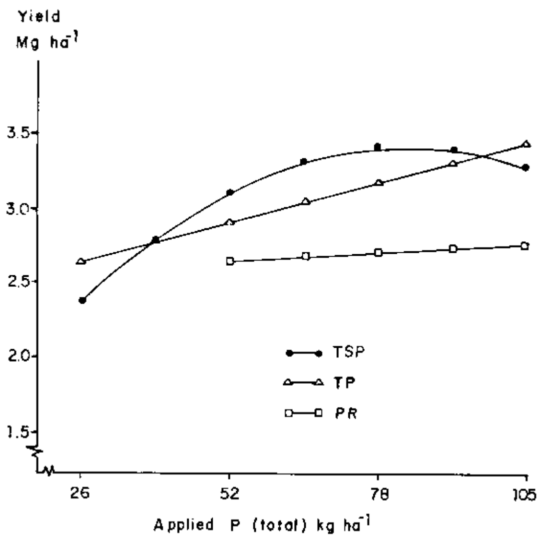

FIG. 1. Annual forage yield (*A. gayanus* & *S. capitata*) with three P levels applied at sown and two lime levels with 0 P level of annual refertilization. Means of three replicates (Sx = 278).

yield obtained with same rate of highest yielding source (TP). Values represented as relative yield (Fig. 2) show lower yield (60 to 80 percent of TP yield) with TSP for 2nd and 3rd year.

Analysis of aerial parts of *Andropogon* grass and *Stylosanthes* legume showed higher Mg content when TP was applied. Although the small amount of lime increased the Mg content in plants, TP sharply increased Mg content with respect to other sources (Table 4). Hence, the higher forage yield obtained during the second and third years with TP should be attributed not only to higher P available to plants but to improved Mg nutrition with this source. The improved efficiency of TSP on time relative to TP was probably the result of improved Ca and Mg nutrition on time due to lime application. However, there was no statistically significant effect lime x source x year.

Effect of lime

The favourable effect of lime on forage yield was significant from first cut after lime application, throughout the years. Lime effect on yield was not dependent on the levels of fertilizer used but on sources of P. The overall lime effects by year for different initial and annual levels of P are presented in Fig. 3. The favourable effect of lime is observed with all sources of P but PR. This was probably the result of PR fertilizer used but on sources of P. The overall lime effects by year for different initial and annual levels of P are presented in Fig. 3. The favourable effect of lime is observed with all sources of P but PR. This was probably the result of PR solubility being affected by lime.

It is apparent from Fig. 3 that lime effect was higher at lowest levels of applied P. This is probably the result of lower levels of Ca and Mg from P sources, at lower levels of P.

The fact that lime effect was significant with both TP and TSP despite the difference in Ca and Mg supplied by the two sources could be the result of increased Ca and Mg availability to plants on time, in this low Ca and Mg content acrustox (Table 5). Further increase in yield could possibly be expected from deeper incorporation of lime and the resulting larger root development due to improved Ca and Mg levels in soil profile (Ritchy et al. 1982).

Forage yield response to annual refertilization

Forage yield response to annualy applied levels (0, 13 and 26 P kg ha^{-1}) depended on P sources but was not affected by year or initial P level. The

TABLE 4. Nutrient content in aerial parts of andropogon grass with three sources of P and two lime levels (second cut, 1980, average of 9 observations).

P Source	P level	No lime				Limed				Forage yield	
		P	Ca	Mg	K	P	Ca	Mg	K	No lime	limed
	kg ha^{-1}	percent of dry matter								kg ha^{-1}	
PR	52	0.09	0.40	0.10	0.84	0.09	0.42	0.12	0.79	1790	1505
PR	104	0.10	0.46	0.07	0.83	0.10	0.47	0.15	0.81	1927	1796
PR	208	0.10	0.48	0.06	0.80	0.10	0.48	0.13	0.76	1818	2022
TSP	26	0.09	0.39	0.07	0.83	0.09	0.39	0.15	0.79	1109	1628
TSP	52	0.09	0.44	0.08	0.80	0.09	0.40	0.16	0.72	1991	2051
TSP	104	0.10	0.48	0.07	0.78	0.12	0.49	0.16	0.78	1796	2150
TP	26	0.08	0.42	0.13	0.83	0.09	0.40	0.19	0.77	1697	2174
TP	52	0.09	0.39	0.16	0.78	0.09	0.38	0.22	0.70	2679	3218
TP	104	0.11	0.39	0.20	0.72	0.11	0.41	0.27	0.67	3075	3942

$S\bar{x}$ = 0.005 (P); 0.03 (Ca); 0.01 (Mg); 0.03 (K). Sx (yield) = 132.

TABLE 5. Exchangeable Ca and Mg in soil samples collected at the end of experiment, at four depths in plots receiving three P sources, two P rates and two lime levels Except for check (n = 3), average of two annual refertilization rates (n = 6).

Depth (cm)	TSP		TP		PR		Check
	Initial P rates kg ha^{-1}						
	26	104	26	104	52	208	0
	Exchangeable Ca + Mg cmol (p$^+$) kg^{-1} No lime						
0 - 15	0.45	0.43	0.61	1.35	0.53	0.71	0.35
15 - 30	0.29	0.28	0.36	0.44	0.30	0.35	0.29
30 - 45	0.22	0.21	0.28	0.35	0.26	0.25	0.27
45 - 60	0.22	0.21	0.26	0.34	0.22	0.21	0.25
	1.6 ton ha^{-1} lime						
0 - 15	0.77	0.88	1.02	1.85	0.88	0.95	0.75
15 - 30	0.40	0.31	0.42	0.53	0.42	0.39	0.41
30 - 45	0.29	0.24	0.34	0.34	0.29	0.26	0.27
45 - 60	0.26	0.22	0.30	0.35	0.25	0.23	0.25

$S\bar{x}$ = 0.07 (n = 6); 0.08 (n = 3).

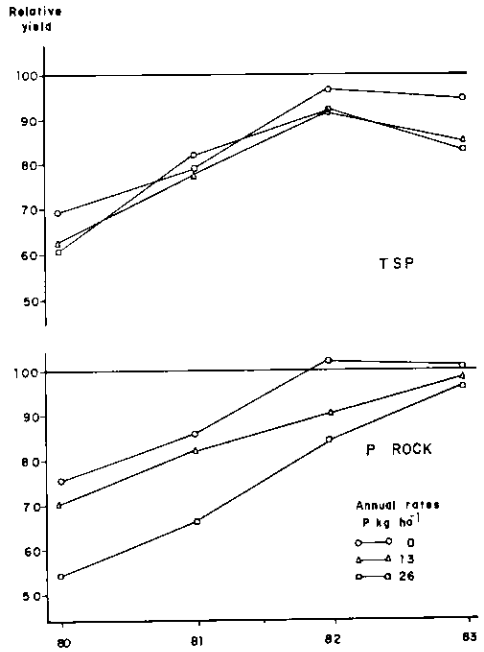

FIG. 2. Relative forage yield with three P sources (2nd to 5th year). TP = 100
TP yield (kg ha^{-1}) = 2372, 1957, 2763 and 2403 (0 P annual rate)
TP yield (kg ha^{-1}) = 2835, 2256, 3180 and 2748 (13P annual rate)
TP yield (kg ha^{-1}) = 3186, 2335, 3830 and 2868 (26P annual rate)
$S\bar{x}$ = 113

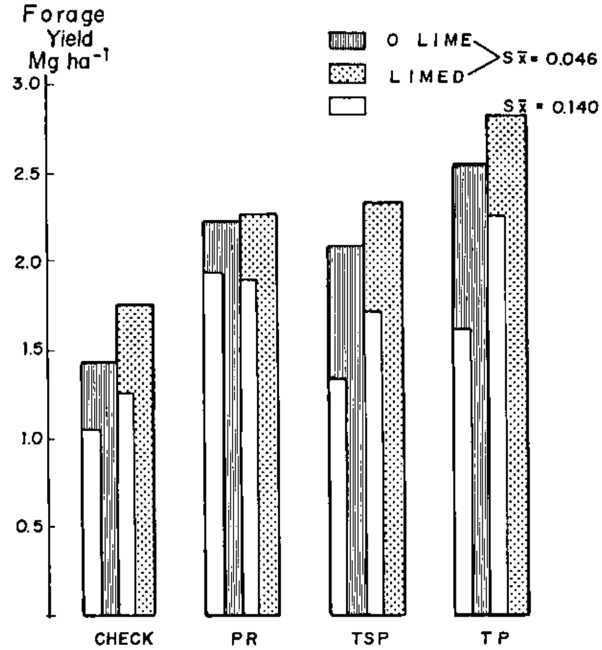

FIG. 3. Effect of lime (1.6 ton ha^{-1}) on forage yield with three sources of P (average of three P initial rates and three annually applied P rates). Blank bars indicate yield of lowest P initial rates with no annual refertilization.

forage yields for different refertilization rates, expressed as relative yield with respect to the yield of 0 level of annual refertilization, are presented in Fig. 4. Relative yields for all three sources (TSP, TP and PR) are averages of three initial P rates (13, 26 and 52 P Kg ha^{-1} for TSP and TP and 26, 52 and 104 for PR). Although initial P rates x refertilization rates interaction was not statistically significant, the examination of relative yields for each initial P level separately, showed a trend towards higher relative yields with refertilization rates applied on plots with lower initial P rates (not shown in Fig. 4). Although there is a clear response to higher annual P rates, the difference in yield obtained with 13 and 26 P Kg ha^{-1} decreased over the years, probably as a result of cumulative effect of annual applications of P. This effect is clearly shown for check plots in Fig. 4, where 26 P Kg ha^{-1} applied annually was significantly better than 13 P Kg ha^{-1} during 2nd and 3rd years but not significantly different thereafter, despite the difference in total P applied over three years (39 vs 78 P Kg ha^{-1}). Results suggest that there is no advantage for annual applications higher than 13 P Kg ha for TSP or TP after third year. In the case of TSP, no response to any annual rate was observed in the 5th year despite the low level of productivity. It appears that by the 5th year, nutrient deficiencies other than P have developed despite nutrients taken up being returned to plots as plant residues. This could be the result of the declining proportion of legume in the pasture after the third year. Previous experiments have shown that the productivity of pure grass pastures under grazing are limited after several years, by N availability. No N fertilizer are used on pastures in the region because of the unfavourable cost/benefits ratios.

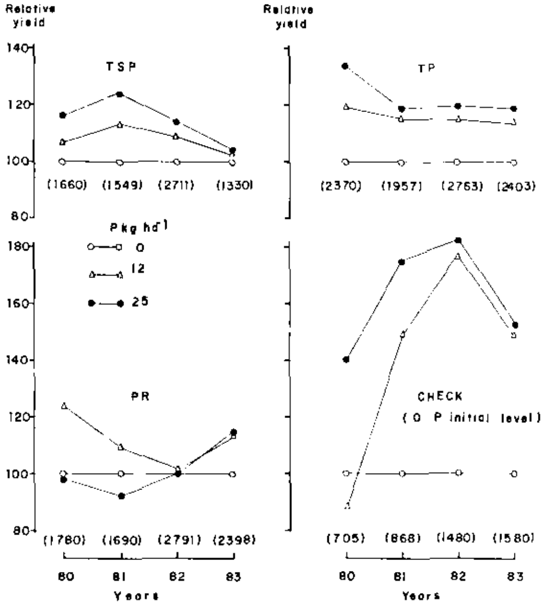

FIG. 4. Relative forage with three P sources and three annually applied P rates (0 annual rate = 100). Averages of three initially applied P rates. Values within parenthesis are actual yield of 0 P annual rate.

CONCLUSIONS

The highest forage yields over the years were obtained with TP. Based on plant composition it was concluded that higher yields obtained with TP were due to higher P available to plants and improved Mg and Ca nutrition. Annual P refertilization treatments produced higher yields than P applied initially, independently of the rate initially applied. This effect was higher during the 2nd and 3rd years and decreased with time. The phosphate rock used in the experiment produced yields similar to those obtained with other P sources applied at half its rate and did not increase significantly at higher P rates. A moderate amount of lime applied on the soil surface improved forage yield with all sources of P but PR despite a higher Mg and Ca content of TP. There was a high response to applied fertilizers but initial rates of growth and annual productivity of the pasture were considerably lower than that observed with similar fertilizer rates and application methods in other oxisols of the region.

Stylosanthes contribution ranged from 10 to 23 percent of total forage yield the first year and from 18 to 31 percent the second year, according to treatments. Annual refertilization rates increased percent legume in forage yield from 22 to 28 percent as an average, for all sources and initial levels of P. Legume yield after 3rd year was negligible, probably as the result of increased competition from *andropogon* grass in the conditions of cutting regime imposed by the experiment.

REFERENCES

ANNUAL REPORT. Tropical Pastures Program, 1980. Cali, CIAT, 1981.

BRAY, R.H. & KURTZ, L.T. Determination of total, organic and available forms of phosphorus in soils. **Soil Sci., 59**:39-45, 1945.

CABALA-ROSAND, P. & WILD, A. Direct use of low grade phosphate rock from Brazil as fertilizer. 1. Effect of reaction time in soil. **Plant Soil, 65**:351-62, 1982.

COUTO, W.; GOMES, D.T.; LEITE, G.G.; SILVA, J.C.S. Legume establishment on native pastures of Cerrados. **Pesq. agropec. bras.**, Brasília, **18**(12):1349-54, 1983a.

COUTO, W.; SANZONOWICZ, C.; BARCELLOS, A. de O. Factors affecting oxidation-reduction processes in an oxisol with a seasonal water table. **Soil Sci. Soc. Am. J., 49**:1245-8, 1985.

COUTO, W.; SANZONOWICZ, C.; LEITE, G.G. Effect of excess water in an oxisol on ammonium, nitrate, iron and manganese availability and nutrient uptake of two tropical forage species. **Plant Soil, 73**:159-66, 1983b.

ESTADOS UNIDOS. Soil Conservation Service. Soil Survey Stoff. Soil taxonomy; a basic system of soil classification for making and interpreting soil surveys. Washington, D.C., USDA, 1975. (Agriculture Handbook, 436)

GOEDERT, W.J. Management of the Cerrado soils of Brazil: a review. **J. Soil Sci., 34**:405-28, 1983.

LE MARE, P.H. Sorption of isotopically exchangeable and non-exchangeable phosphate by some soils of Colombia and Brazil, and comparisons with soils of southern Nigeria. **J. Soil Sci., 33**:691-707, 1982.

MCLACHAN, K.D. Nutrient problems in sown pastures on an acid soil 3. Thermal phosphates. **Aust. J. Exp. Agric. Anim. Husb., 21**:318-25, 1981.

NELSON, W.L.; MEHLICH, A.; WINTERS, E. The development, evaluation and use of soil tests for phosphorus availability. In: PIERRE, W.H. & NORMAM, A.G. eds. **Soil and fertilizer phosphorus.** Madison, Am. Soc. Agronomy, 1953.

RITCHEY, K.D.; SILVA, J.D.; COSTA, U.F. Calcium deficiency in clayey B horizons of savana Oxisols. **Soil Sci., 133**:378-82, 1982.

SMITH, T.J. & SANCHEZ, P.A. Effects of lime, silicate and phosphorus applications to an Oxisol on phosphorus sorption and ion retention. **Soil Sci. Soc. Am. J., 44**(3):500-5, 1980.